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Energy-saving Technologies in Transportation of Natural Gas Facilities

Tamara Datsuk[a], Gari Pozin[b], Vera Ulyasheva[a *], Mikhail Kanev[a]

[a]Saint-Petersburg State University of Architecture and Civil Engineering, 4, 2-nd Krasnoarmeiskaya st., 190005, Saint-Petersburg, Russia

[b]St.-Petersburg State University of Technology and Design, 191186, St. Petersburg, Russia

Abstract

This paper is devoted to the various sources of secondary energy resources on gas transportation facilities. The modern numerical methods are used in heat and air exchange processes research based on the Navier-Stokes equations. The principles and automation diagrams of environmental support systems are presented.

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Keywords: compressor station, gas turbine unit, secondary energy resources, heat source.

1. Introduction

Creating normalized parameters of the indoor environment with the usage of energy-efficient technologies is one of the important trends in the building industry [1,2]. The existing tendency of the increased cost of energy fosters energy-saving measures in the transport of gas, in particular, towards the use of secondary energy resources [3,4].

To maintain design capacity of the main gas pipelines industrial sites, including linear industrial management with 1-2 compressor station (CS), office buildings, energy-heat and water objects and service vehicles [5] are constructed every 120-150km on the track. In the northern parts of the country gas turbines are mainly used as drive gas compressors. The feature of gas turbine units (GTU) is low efficiency (28-32%). For heat utilization of exhaust gases gas ducts are installed on the gas-water heat exchangers. According to the results of studies of labor

* Corresponding author. Tel.: +7-812-575-0534; fax: +7-812-316-5872.
E-mail address: ulyashevavm@mail.ru

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conditions, made with the participation of the authors in accordance with regulatory requirements [6, 7], about 20% of the jobs are classified as conditionally certified due to the inconsistency of microclimate parameters with normalized values [5]. A significant number of these jobs are related to the instability of the heating system by utilizing heat exchangers.

2. Literature review

A number of papers, for example [8-12], are dedicated to the search for energy saving technologies based on secondary sources of internal heat, including climate systems. Conversion of the secondary energy resources (SER) into the thermal energy is not only sufficient to satisfy the needs of compressor stations (CS) in heat supply but also external customers. The heat of gas turbine exhaust gases can be used for technological purposes as well, such as to heat water or generate steam supplied into the flow of the gas turbine which makes it possible to increase capacity of a gas pumping unit (GPU). The consumers of the heat at CS include compressor and repair shops, machine shops, auxiliary power, household et al., as well as external customers. Availability of the external customers (residential settlements, agricultural consumers, etc.) near the CS-party makes it possible to increase the proportion of recycled heat up to 25%. As noted above, the relatively low efficiency of the gas turbine determines the annual irretrievable loss of about 25-30 billion m3 of natural gas with a temperature of combustion products bearing about 1 million tons of nitrogen oxides and about 200 thousand tons of carbon oxides.

3. Methods and schemes

Short , the main source of secondary energy resources (SER) are the exhaust gases from the gas turbine. In addition, to the sources of heat resources can also be carried [13]: lubricating oil cooling systems; cooling gas systems; heated surfaces of the gas ducts and gas turbines in the engine rooms of the COP; physical energy of throttled fuel gas. Thus, despite of the fact that the heat of the exhaust gas is most easily disposed for heating purposes, this direction does not make it possible to use all the resources of the associated heat at CS. The internal loads and external consumers do not provide any stable and energy-intensive consumption of the low degree heat.

Using the secondary heat CS to meet more stable and energy intensive external consumers of heat, makes it possible to refuse the construction of additional boilers. However, sometimes the compressor stations are located at a considerable distance (5-15km) from the most stable consumers, making it necessary justification for the limit radius heating, the distance at which the transport of the utilizable heat is cost-effective. Thus, due to the lack of stable and energy intensive consumers of the low degree heat, the recovery of the heat of exhaust gases GTU only for heating purposes does not completely solve the problem of the associated heat utilization at the CS main pipeline. In addition, the experience of operating water heating systems shows that their operation is disrupted for many reasons, including:

- reduced heating capacity of utilizing heat exchangers due to the scale formation inside the tubes in the absence or low quality of chemical water treatment,
- mismatched characteristics of the heat generating equipment with estimated ones and as a result, the insufficient heating system capacity,
- absence of highly technological schemes of water draining from the system with a high level of automation at emergencies,
- prolonged loss of efficiency and complexity of the reintroduction into work during emergency stops of the heat sources.

The aforementioned reasons can be the cause of heating and ventilation systems defrosting and, as a consequence, the failure of heaters, pipes, fittings, etc. One of the ways to ensure stable operation of these systems is introduction of automation systems, which basic diagram is shown in Fig. 1. The diagram of heat recovery unit is shown in Fig. 2.

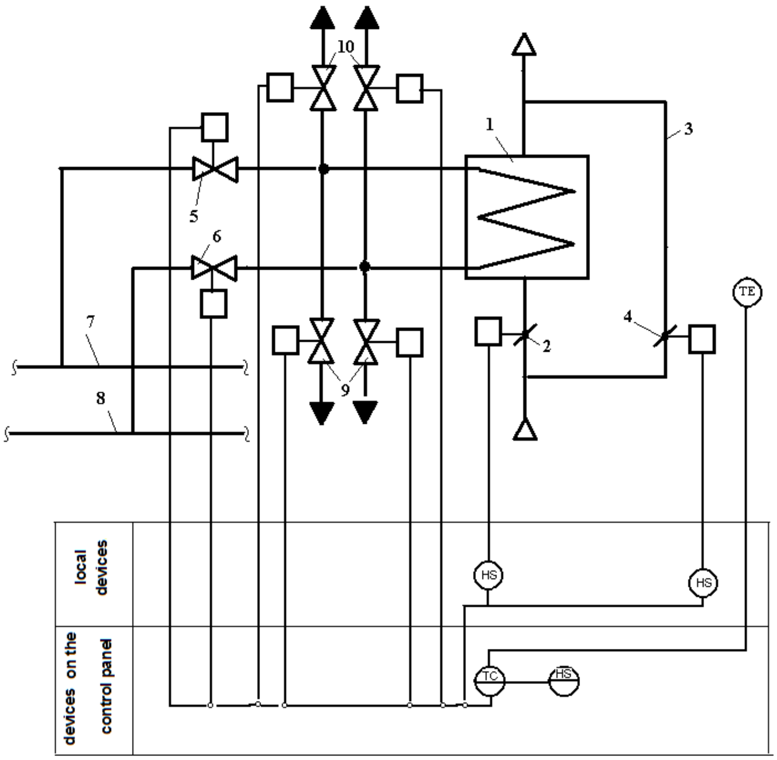

Fig. 1. Principled diagram of the automatic control of the heat recovery of exhaust gases

1 – waste heat, 2 – utilizer valve, 3 – bypass, 4 – bypass valve, 5, 6 – waste heat disconnection valves, 7 – supply pipe, 8 – return pipe, 9 – drain valves, 10 – air valves

A utilize heat exchanger can be presented as subject to regulation which takes the heat of the exhaust gases at the input and at the output the current value of the controlled variable – heat carrier temperature – is determined. For external consumers heating the heat carrier temperature must be linked with external perturbations (outside air temperature, wind speed and direction), i.e. a heating schedule must be built. The regulatory body is a block of valves installed in front of the heat exchange modules and the bypass channel. These dampers reallocate the exhaust flow according to the following algorithm: the heat exchange modules open, the bypass is covered up – the heat removal increases, the temperature of the heat carrier at the outlet of utilizer grows – the maximum heat removal is provided by full opening of the valves to modules and closing of the valves to bypass – the reduction of the heat removal is provided (reduction of the heat carrier temperature) by the reverse rotation of the valves, i.e. the valves in front of the heat exchange modules close, whereas the bypass opens.

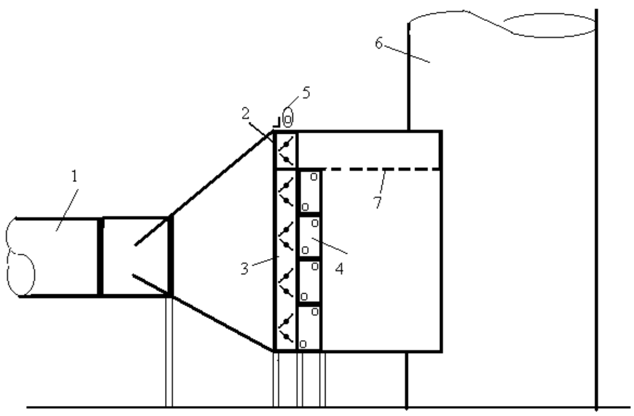

Fig. 2. GTU exhaust gases heat recovery system

1 – gas flue, 2 – bypass channel valve, 3 – waste heat valve, 4 – utilizers, 5 – actuator,

6 – exhaust pipe, 7 – septum

Automation systems for controlling the heating capacity of heat exchangers utilizing different GTU differ in the number of the actuator elements mounted on the block valves.

For example, as a regulator "electronic temperature controller ERT-1" designed to automatically adjust the heat supply, forming a proportional-integral control law and having a neutral zone no more than 0.5 °C has been applied. After the reconciliation signal has been selected, the regulator generates output impulses interspersed with pauses. The duration of the first impulse (the proportional part) depends on the error value, whereas the integration of the subsequent impulses gives an integral part of the time constant control 100-500s. The heat curve is laid in the controller as a reference via the slope coefficient in the range 1-4.

The automatic control system makes it possible to carry out such operations:

"Start" from the automatic board or according to the output GTU signal to the normal operation. The following will occur in this case: the valves to the lintel between the direct and the drain piping and the valves between the reverse and the drain piping will close: the vent valves will open; the drainage will open; the air vent and drainage will close after the sensor signal about the presence of water at the outlet of the air vent; the gate valves before the heat exchanger modules will slightly open and in a certain time delay the temperature of the coolant will automatically start regulating. If the gas turbine is not in operation, the valve to the lintel between the direct and the recirculation line will open, whereas the valve at the outlet of the heat exchanger will close.

"Short Shutdown" – from the automatic board or according to "emergency stop" signal from GPA. This will open the gate valves before the flue gas bypasses; the gate valves will close before the modules; the valve to the lintel between the direct and the recirculation line will open; the valve at the outlet of the heat exchanger will close.

"Normal Shutdown" – from the automatic board. In this case the gate valves before the bypass and the heat exchangers will be set to the starting position, the valves at the inlet and the outlet of the heat exchanger will close with a time delay; the drainage and the vent valves will open; the valves between the direct and the drain piping as well as the valves between the drain and the reverse piping will open. A discharge of water from the heat exchanger will occur.

"Emergency Shutdown" – from the board signal or any alarm that foresees the discharge of water of the heat exchanger and its shutdown.

As previously mentioned, in the heat recovery systems for the exhaust gas at the compressor stations, the automatic process control of utilization is practically not used. One of the main reasons for this is the absence of adjusting characteristics of the utilization process control valves.

In order to maintain constancy of the hot gases total flow in both channels and, accordingly, of the stability of the pressure loss in the gas outlet path, work involving the construction of adjusting characteristics of the valves in the bypass channel and the channel-heat exchangers was done. Evaluation of the flow amount was performed according to the relative terms Lb and Lu, the values of which are expressed through the relationships:

$$\overline{L}_b = \frac{L_b}{L_b^{\max}}, \quad \overline{L}_u = \frac{L_u}{L_u^{\max}}, \qquad (1)$$

where Lb – exhaust flow through the bypass channel,

Lu – exhaust flow through the heat exchangers.

The results of the research are shown in graphic form in Fig. 3.a and 3.b.

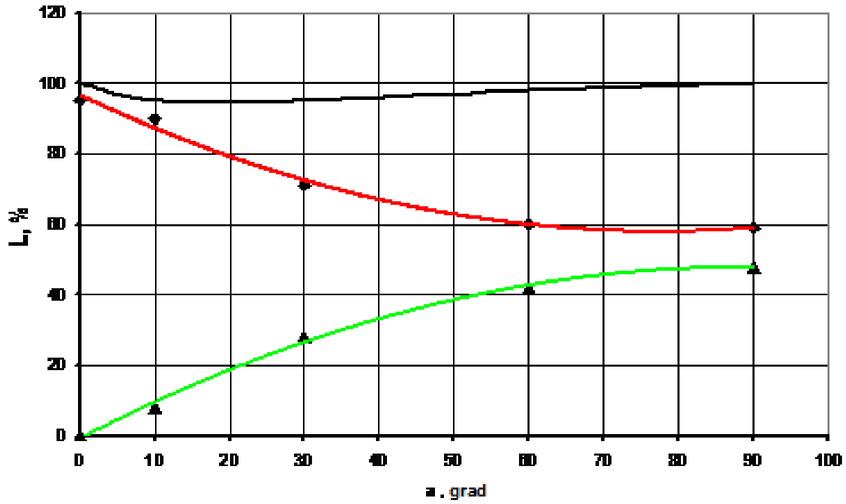

Fig. 3.a Adjusting characteristics of the valves for the two-row heat exchanger

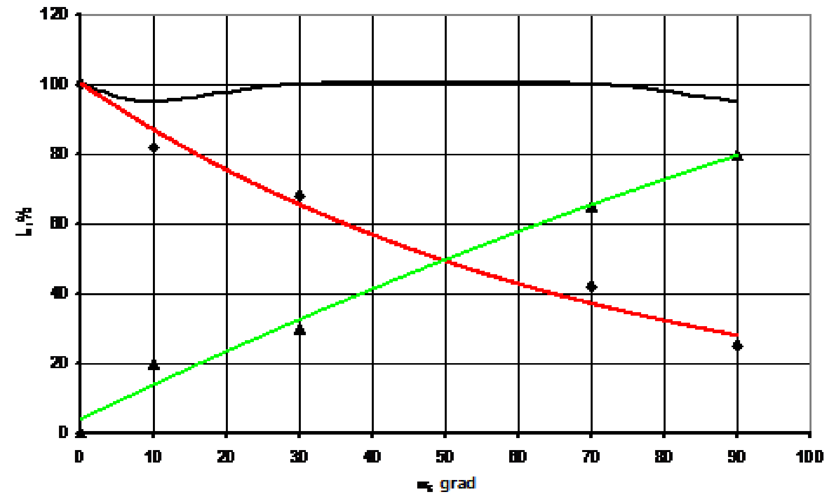

Fig. 3.b. Adjusting characteristics of the valves for the three-row heat exchanger

To determine the exhaust parameters the measuring thermo-anemometric complex TESTO 454 is used, which makes it possible to measure not only the temperature and flow velocity, but also the concentrations of the individual components of the combustion products. The measurements were carried out at four positions of the valve blades inclination angle for the two- and three-row heat exchangers. The research results made it possible to obtain the control characteristics of the valves designed for practical use.

Additionally, it should be noted that the instability of the water system of the exhaust gases heat utilization results to significant difference of the microclimate parameters. The latter circumstance leads to analyze the possibility of using other sources of heat, such as hot surfaces of equipment. The heat can be used for machine rooms, superchargers' galleries, gateways etc., which in combination with traditional recovery systems will reduce the load on the main recovery systems and ensure the stability of the microclimate due to the simplicity of regulation of the internal air recovery systems. To ensure the microclimate parameters in CS machine rooms, when heat utilization from the heated surfaces is used, it is advisable for the system to combine the functions of heating and ventilation, and in some cases, to provide the use of heat for technological needs. First of all, the easiest way, as shown by the analytical review in the work [13], is the use of recirculation, taking into account the requirements of normative documents [1]. With the participation of the authors blowing systems of the heated surfaces are offered to heat the lower zone space in the cold season and blow out convective jets from the work area of the maintenance platform [5]. In this case the outside air is supplied only according to the conditions of compliance with health standards, and the ventilation system does not provide for supply of recirculated air in the supply air chamber. It reduces the metal consumption of the system, considering the space-planning decisions of compressor stations. The principled diagrams of convective flows are presented in [5]. Quantitative characteristics of this process are derived from the widespread currently numerical simulation [14-23] of the system of differential unbrokenness equations, the Navier-Stokes equations, conservation of heat amount and impurities (moisture content of the air):

$$
\begin{aligned}
&\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial X_j}\left(\rho u_j\right)=s_m,\\
&\frac{\partial \rho u_i}{\partial t}+\frac{\partial}{\partial X_j}\left(\rho u_j u_i-\tau_{ij}\right)=-\frac{\partial P}{\partial X_j}+s_i\\
&\frac{\partial \rho C_P T}{\partial t}+\frac{\partial}{\partial X_j}\left(\rho C_P T u_j\right)=\frac{\partial}{\partial X_j}\left(\lambda\frac{\partial T}{\partial X_j}-\rho C_P\overline{u'_j T'}\right)\\
&\frac{\partial \rho c}{\partial t}+\frac{\partial}{\partial X_j}\left(\rho c u_j\right)=\frac{\partial}{\partial X_j}\left(\rho D\frac{\partial c}{\partial X_j}-\rho\overline{u'_j c'}\right)
\end{aligned}
\qquad (2)
$$

where t – time; $X = X_{i,j,k}$ – coordinates; $u = u_{i,j,k}$ – components of the velocity vector; P – pressure; C_P, ρ – specific heat and density; $\tau_{i,j}$ – components of the stress tensor; s_m, s_i – the source of mass and impulse source components; λ, D – coefficients of thermal conductivity and diffusion.

In the work [23] two technical solutions of heat recovery of the heated surfaces, depending on the features of arrangement of the gas pumping units – individual and multimachine – and developed with the participation of the authors are also presented. Fig. 4 shows the automation diagram of the heat recovery system of exhaust air from the turbine room with the group installation of gas turbine units. In the diagram the "air-air" heat exchanger is provided to heat the supply air in the superchargers room. Regulators of the heating capacity of the heat exchanger-regulation are used by changing the flow of hot air. The diagrams involving the usage of the exhaust air heat from the multimachine room to heat the supply air for gateways and the machine room itself have also been designed. Any of the recuperative heat exchangers may be used in the diagram.

A distinctive feature of the individual assembly of the gas pumping units is a sharp change in the thermal regime of the turbine hall, depending on the operating mode. In operating mode – the thermal regime is characterized by a significant thermal stress in the reserve and repair period – a room with heat deficiencies. The automation diagram of the utilizing systems is shown in Fig. 5. For the group of such objects the following variants of utilization are offered:

- a single circuit of air heating, which provides a single duct of the heated air from the machine running, in this case the heat exchangers are installed directly before entering the rooms serviced;

- a single supply air duct, which is heated by the heat exchangers and local air heaters installed on the exhaust air duct.

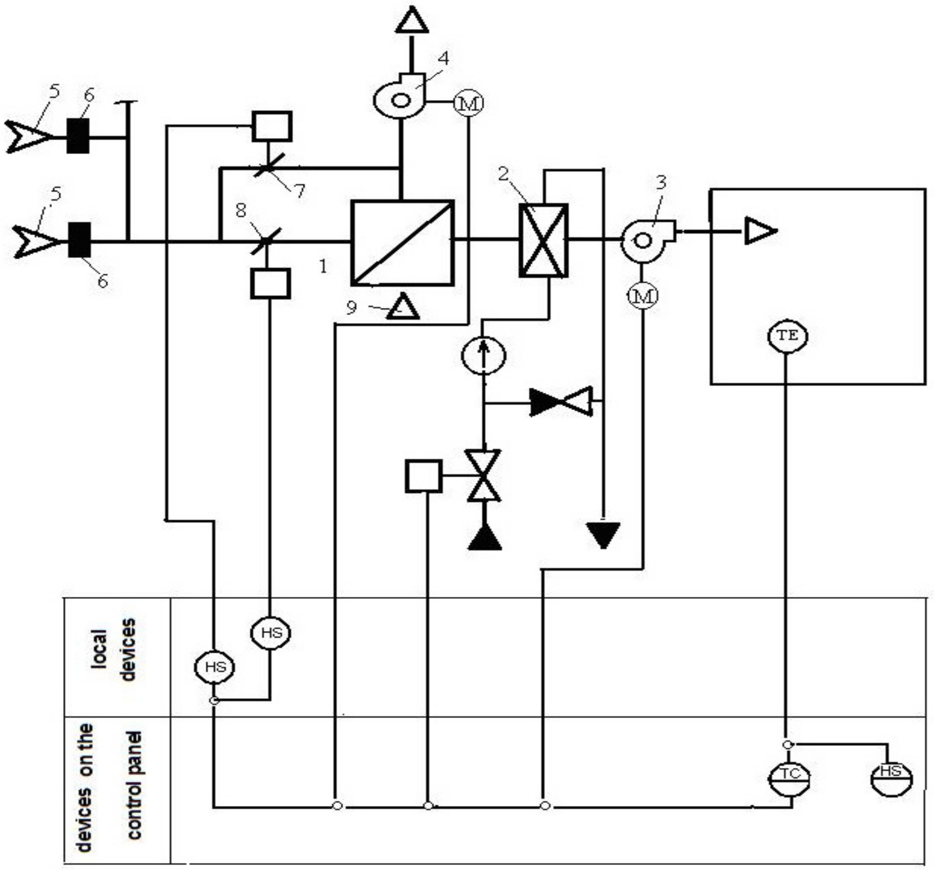

Fig. 4. Principled automation diagram for the multimachine room

1 – utilizer, 2 – air heater, 3 – supply air fan, 4 – the exhaust fan, 5 – local pumps (exhaust devices), 6 – fire damper, 7 – bypass valve, 8 – recovery valve, 9 – external air

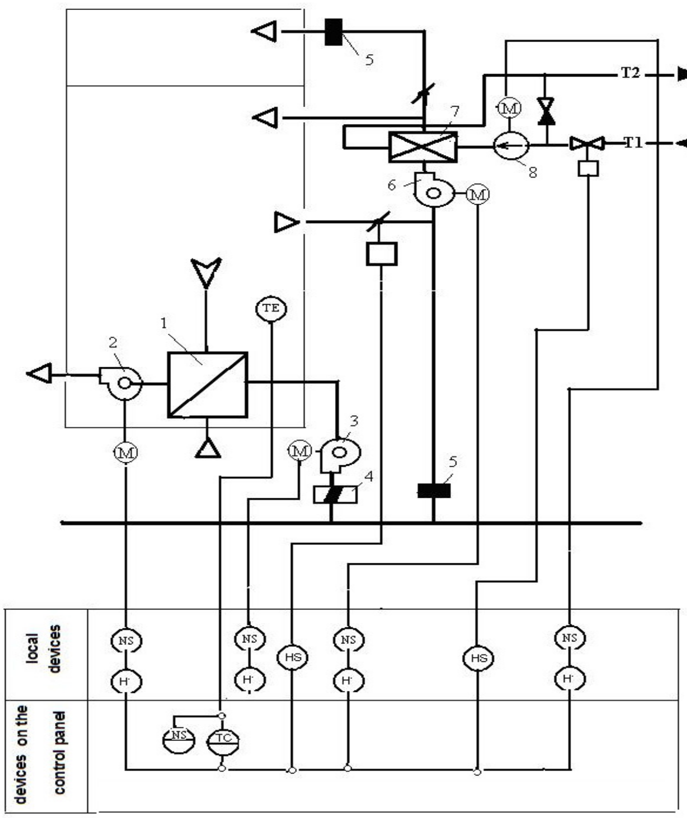

Fig. 5. Principled automation diagram for individual hideouts

1 – utilizer, 2 – exhaust fan, 3,6 – supply fans, 4 – return valve, 5 – fire damper, 7 – air heater, 8 – pump

4. Conclusions

1. Studying labor conditions at the existing compressor stations of the main gas pipelines made it possible to reveal problems with ensuring normalized parameters of the microclimate in the workplace and the potential sources of secondary energy resources.
2. The principles of the rational organization of air exchange and heat utilization with the placement options for different power units in machine rooms of compressor stations of gas mains, used in practice, and principled automation diagrams of their work have been devised.

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